Higher speed demodulation of fiber grating sensors

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ABSTRACT

For very high-speed events, such as ballistics testing, strain measurement speed is not limited by the response of the fiber grating sensor, but rather the demodulation system used. This paper focuses on a current 10kHz fiber grating demodulator used to support impact and ballistics testing of a composite panel. It also explores the next generation demodulator, pushing the limits of speed upwards of 3Mhz.

Keywords: Fast, strain, ballistics, composite panel, impact

1. HIGH-SPEED DEMODULATION

There are many applications where the high-speed demodulation of fiber grating strain sensors is necessary (Figure 1.) In the aerospace industry, in-flight health monitoring; In civil structures, traffic monitoring [1]. Others include vibration, wave propagation and oversampling.

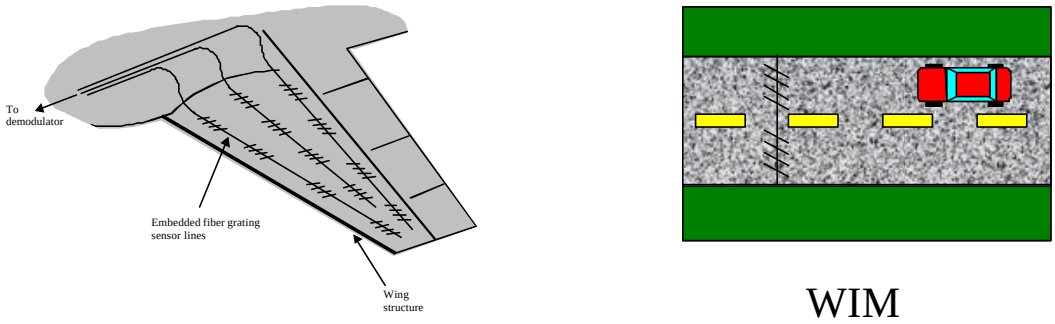

Figure 1. Applications for high-speed demodulation of fiber grating sensors

2. CURRENT TECHNOLOGY

In response to these high-speed demodulation needs, Blue Road Research designed and built a prototype fast fiber grating demodulator based on using a chirped fiber grating spectral filter [2-4]. Currently, the demodulation box (Figure 2) has 10kHz capability. Figure 3 shows a frequency roll off (f_0) at approximately 13 kHz for the current demodulator.

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Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE	2. REPORT TYPE	3. DATES COVERED
1999		**00-00-1999 to 00-00-1999**

4. TITLE AND SUBTITLE	5a. CONTRACT NUMBER
Higher speed demodulation of fiber grating sensors	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Blue Road Research,2555 NE 205th Avenue,Fairview,OR,97024**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S)
	11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES
The original document contains color images.

14. ABSTRACT
see report

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			
unclassified	**unclassified**	**unclassified**		**9**	

Figure 2. Blue Road Research fast fiber grating demodulation box, currently with 10 kHz capability.

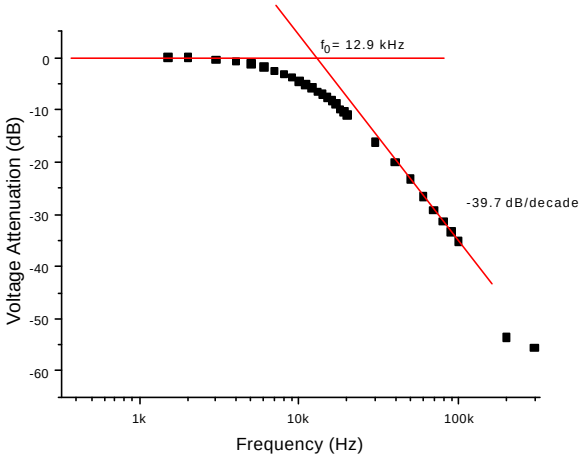

Figure 3. Measured frequency response of the current fast demodulator.

This demodulation box has been used to support several tests including ballistics, impact, and load to failure on concrete [5] and composites. The latest of these tests are impact and ballistics testing of composite panels.

3. IMPACT AND BALLISTICS TESTS

As part of an Army Research Lab program to study composite armor smart structures, a panel with embedded fiber grating strain sensors was subjected to impact and ballistics tests.

3.1. Impact Tests

The impact tests consisted of dropping a chisel from varying heights onto a composite armor panel. These second series of tests (details on the first series of tests can be found in [2]) used the Blue Road Research fast demodulation box. Data from the tests can be seen in Figure 5 - Figure 7. Due to limitations on the data acquisition card running multiple channels, the sampling occurred at 2.5kHz.

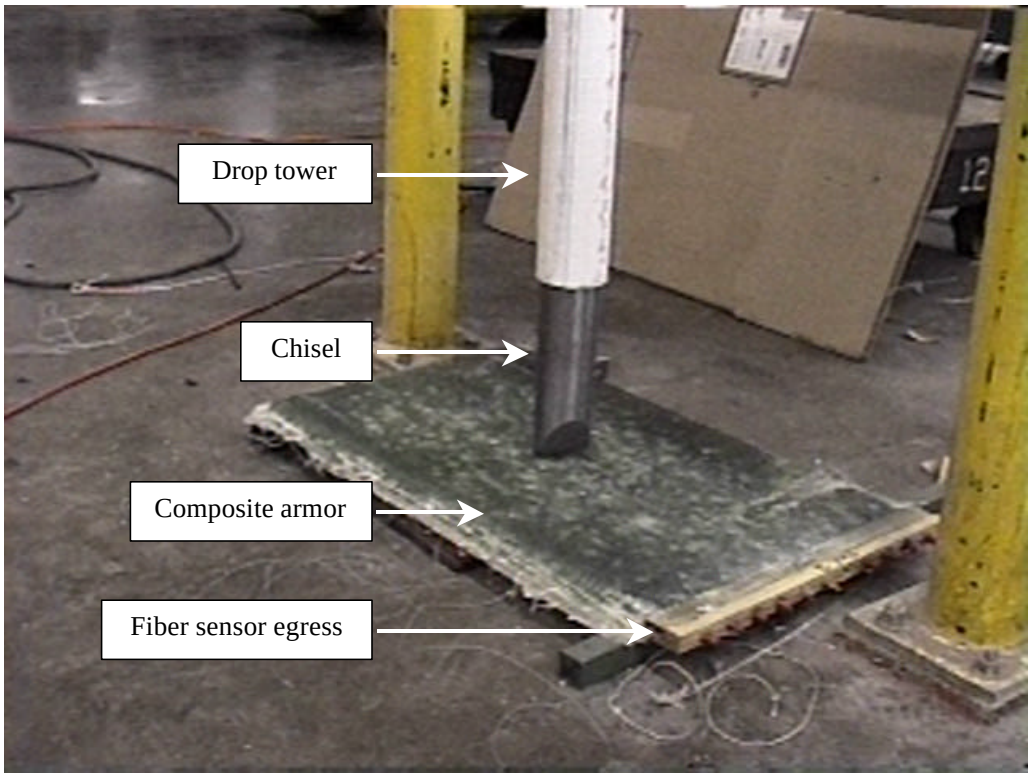

Figure 4. Impact testing of composite smart armor with embedded fiber grating strain sensors.

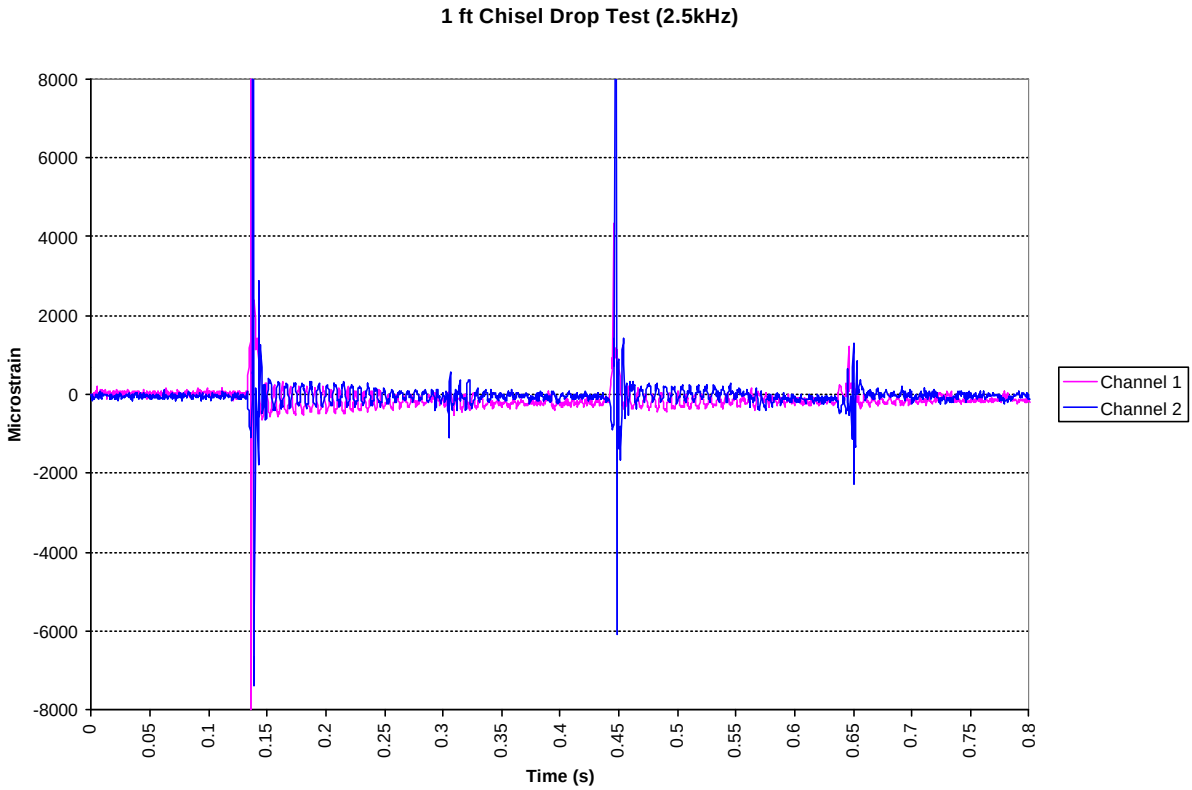

Figure 5. Fast (2.5kHz) demodulation of chisel dropped from 1 foot above composite panel with embedded fiber grating strain sensors.

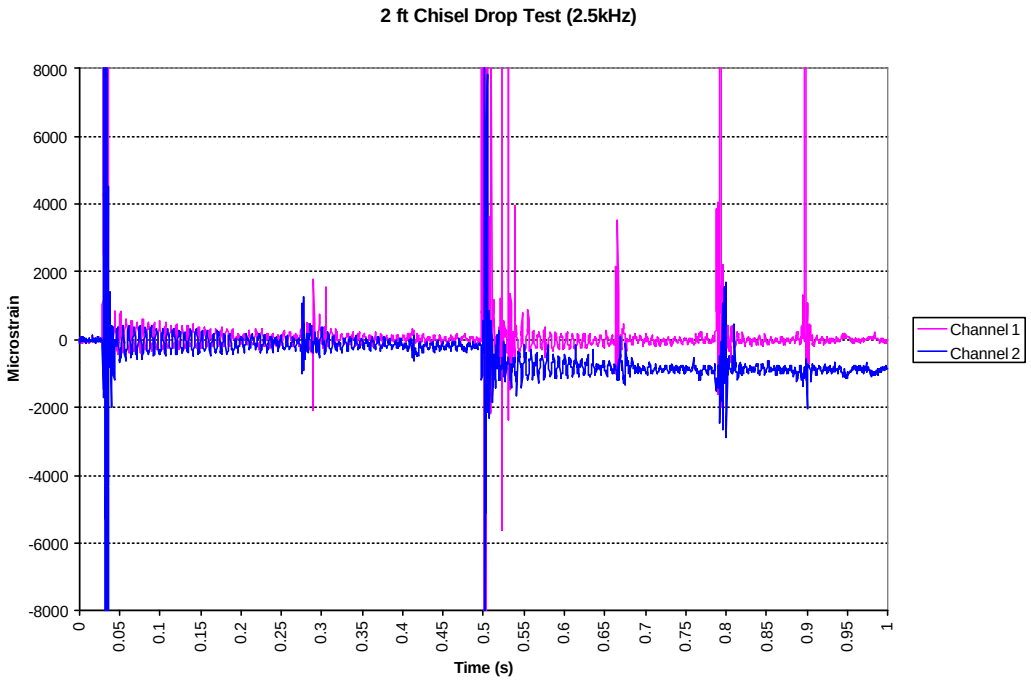

Figure 6. Fast (2.5kHz) demodulation of chisel dropped from 2 feet above composite panel with embedded fiber grating strain sensors.

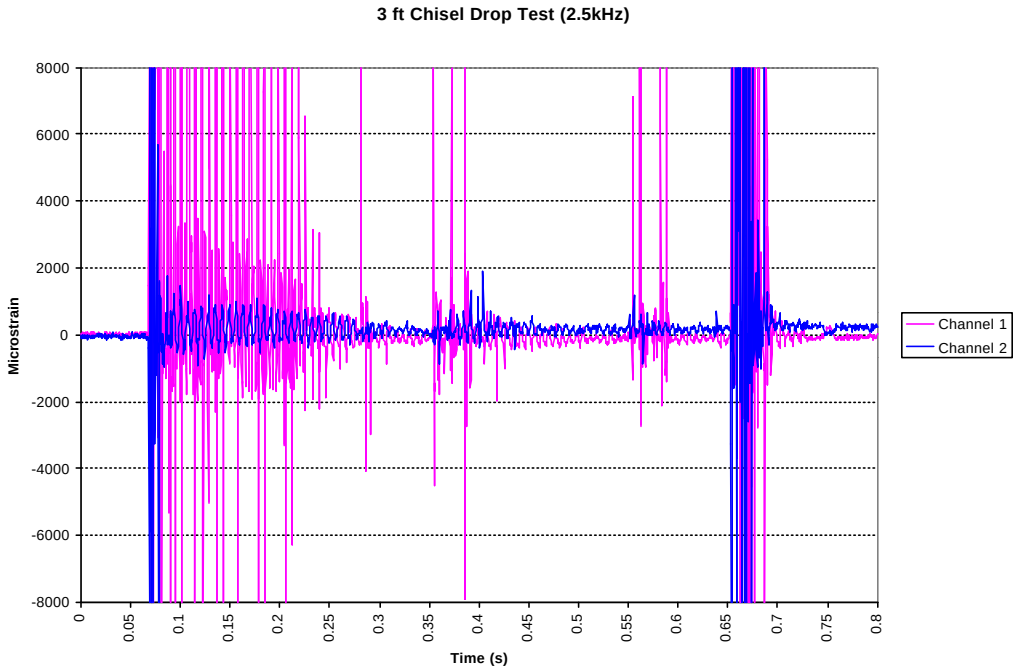

Figure 7. Fast (2.5kHz) demodulation of chisel dropped from 3 feet above composite panel with embedded fiber grating strain sensors.

3.2. Ballistics Testing

The composite armor was also subjected to ballistics testing. Figure 8 shows the panel and test area prior to ballistics testing. The composite panels were shot with a 22 and with 9mm shells. Figure 9 shows the panel after two 9mm rounds were fired.

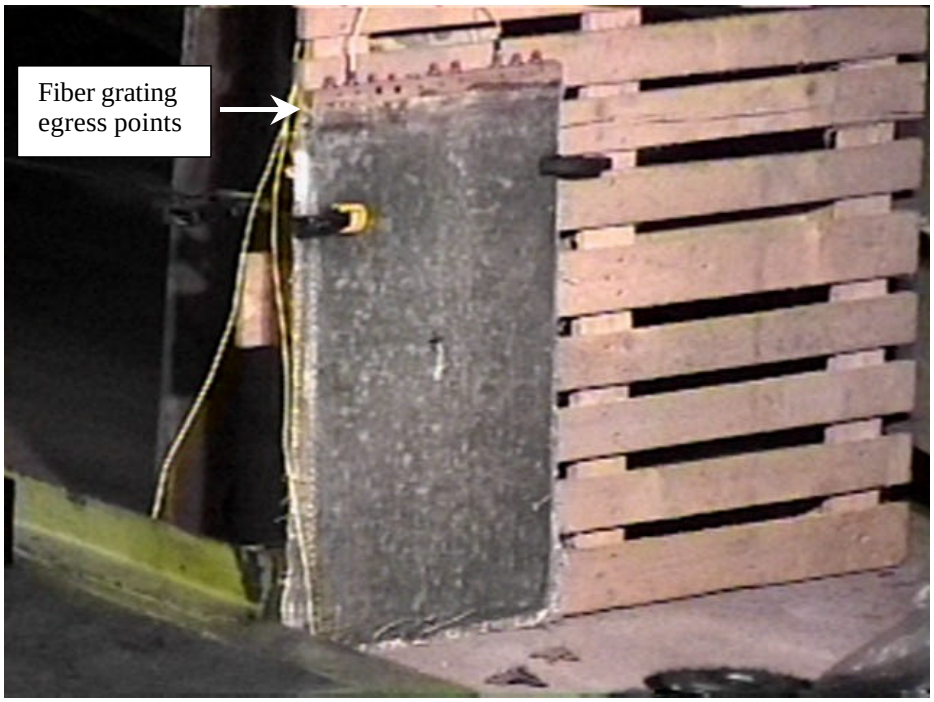

Figure 8. Composite smart armor with embedded fiber grating strain sensors prior to ballistic tests.

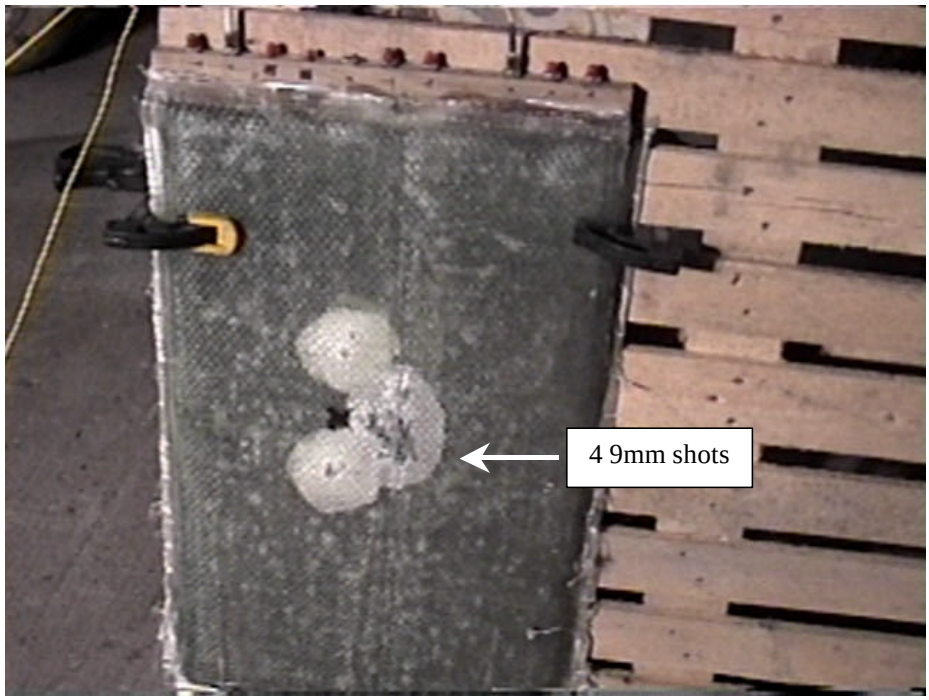

Figure 9. Composite smart armor after 4 9mm shots.

Figure 10 shows the back side of the panel after ballistics testing. Figure 11and Figure 12 show data from the ballistics tests.

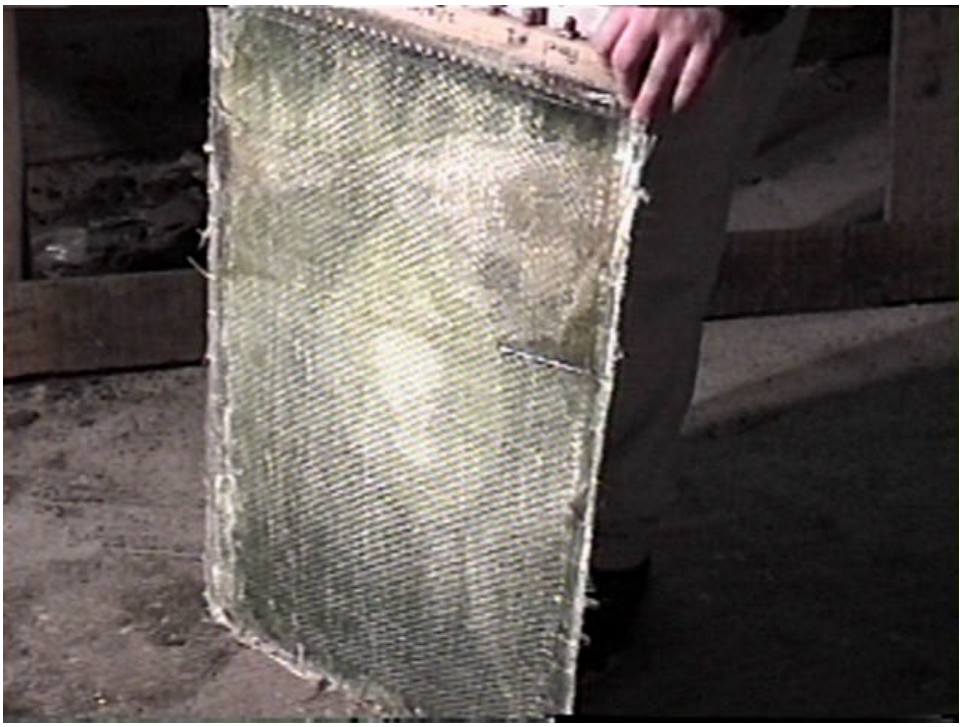

Figure 10. Back side of composite smart armor after ballistics testing

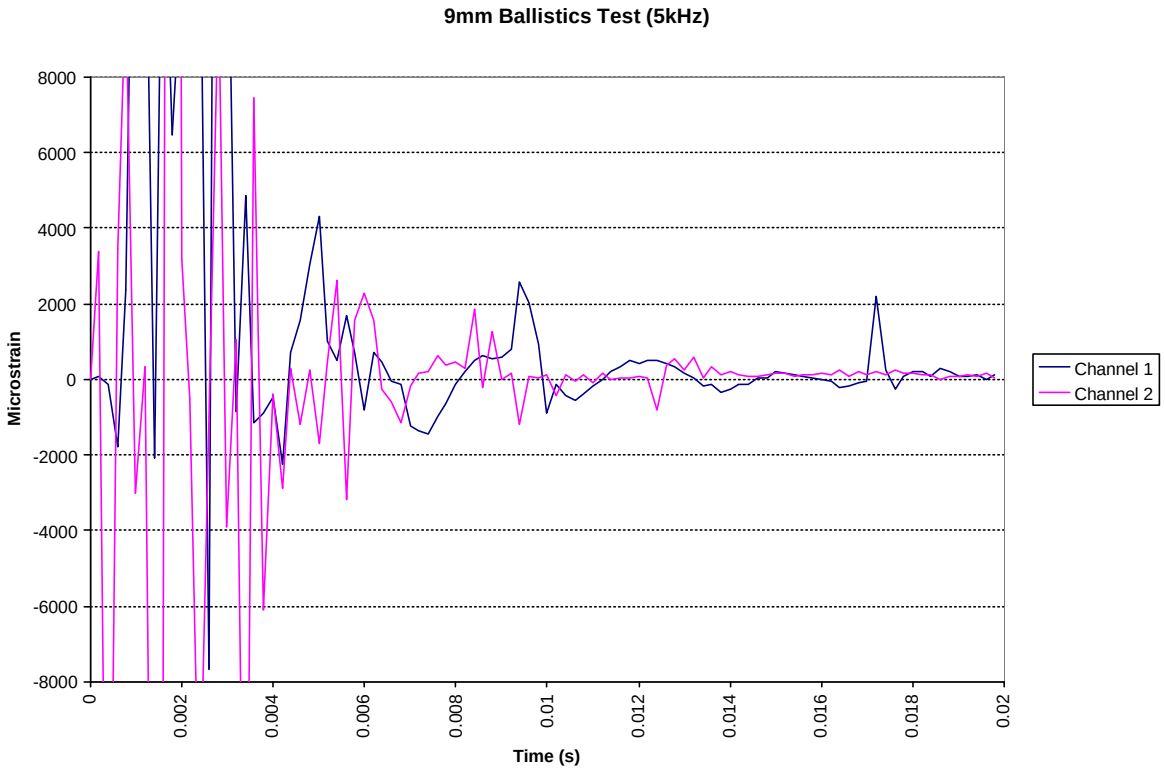

Figure 11. Ballistics test (5kHz) with 9mm shell on composite panel with embedded fiber grating strain sensors.

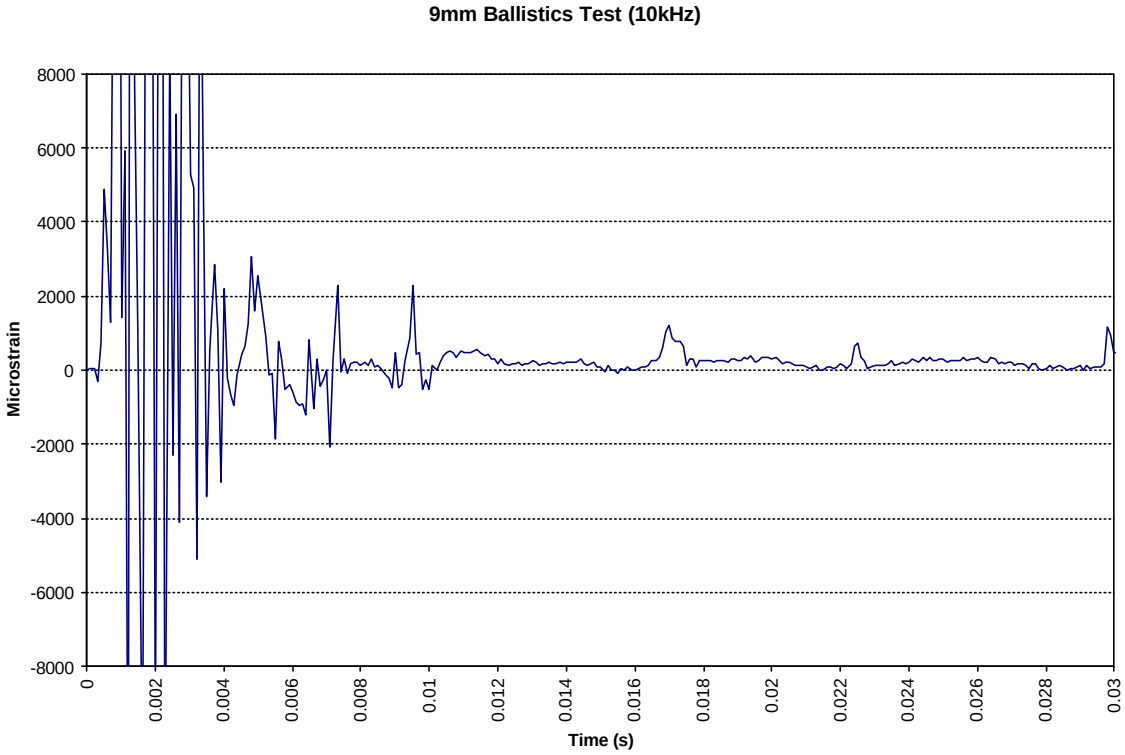

Figure 12. Ballistics test (10kHz) with 9mm shell on composite panel with embedded fiber grating strain sensors.

4. HIGHER SPEEDS

For certain applications such as ballistics testing, speeds higher than the current 10kHz are desired. A reasonable limit for the speed of a fiber grating demodulator of this type is 10MHz. There are several tradeoffs associated with this.

The first and perhaps most limiting tradeoff is sensitivity. The higher the speed, the lower the sensitivity. Another tradeoff with higher speeds is the demodulator's ability to measure steady state events. Cost is another obvious tradeoff.

5. FUTURE WORK

Blue Road Research's next efforts will be to construct a 3 MHz version of its fast fiber grating demodulator to further support ballistics tests. Blue Road will also be working on multiple channel versions operating at both speeds.

6. ACKNOWLEDGEMENTS

The authors would like to thank the Army Research Lab for its support and funding under the "Liquid Molded Composite Armor Smart Structures Using Embedded Sensors" program.

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